Inexhaustible CO_2 Eliminators: Large Scale Unit and Inert Gas Losses

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LONG-TERM GOALS

To study the feasibility of using membrane separation technology to devise an inexhaustible CO_2 eliminator for use in divers breathing apparatus.

OBJECTIVES

To manufacture and test prototypes of CO_2 eliminator units made of hollow fibers of the type used in membrane separators. The CO_2 is eliminated by dissolving it into the surrounding water, thus making the elimination process continuos and inexhaustible. Different fiber types are to be tested at different water temperatures and rates of gas flow through the fibers and water flow past the fibers. A large-scale unit is to be built using the best performing fiber. The rate of inert gas loss or gain is to be determined. Preparations will begin to test units at different simulated diving depths.

APPROACH

Manufacture exchange units using different types of fibers. In the laboratory, immerse each exchanger unit in water and make the water move past it. Make gas which is similar in composition to what a person exhales (4% CO_2, 18% O_2 in N_2) flow through the exchanger. Analyze the gas that leaves the exchanger (retentate) by mass spectrometer to determine the CO_2 and O_2 fractions. Vary the water and gas flows independently. Vary the water temperature and salinity to determine the performance during different environmental conditions. Vary the spacing between the fibers in an exchanger unit. A large-scale unit will be built and it will be about 100 times bigger than the single layer units tested previously. This will be accomplished by combining 10 units that have 10 layers of fibers each.

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Key Individuals

Dr. Claes E.G. Lundgren and Dr. Dan E. Warkander are the investigators. Dr. Alexander Stern started the project at Syracuse University and is now acting as a consultant. Mr. Bruce Laraway and Mr. Andrew Barth built the exchanger units, modified the testing tower and performed actual measurements.

WORK COMPLETED

During FY98 work has been concentrated in the following areas (some elaboration is below):

- Obtained and tested more types of fibers.
- Completed tower modifications tests for determination of inert gas losses; Experiments are ongoing.
- Obtained the fibers for the large-scale unit and manufacturing has started.
- Obtained the material for a smaller testing tower required for tests in a hyperbaric chamber.

RESULTS

Effects of Temperature and Fiber Type on Exchanger Efficiency

Figure 1 illustrates the effect of water temperature and water flow on the performance of three different types of fibers.

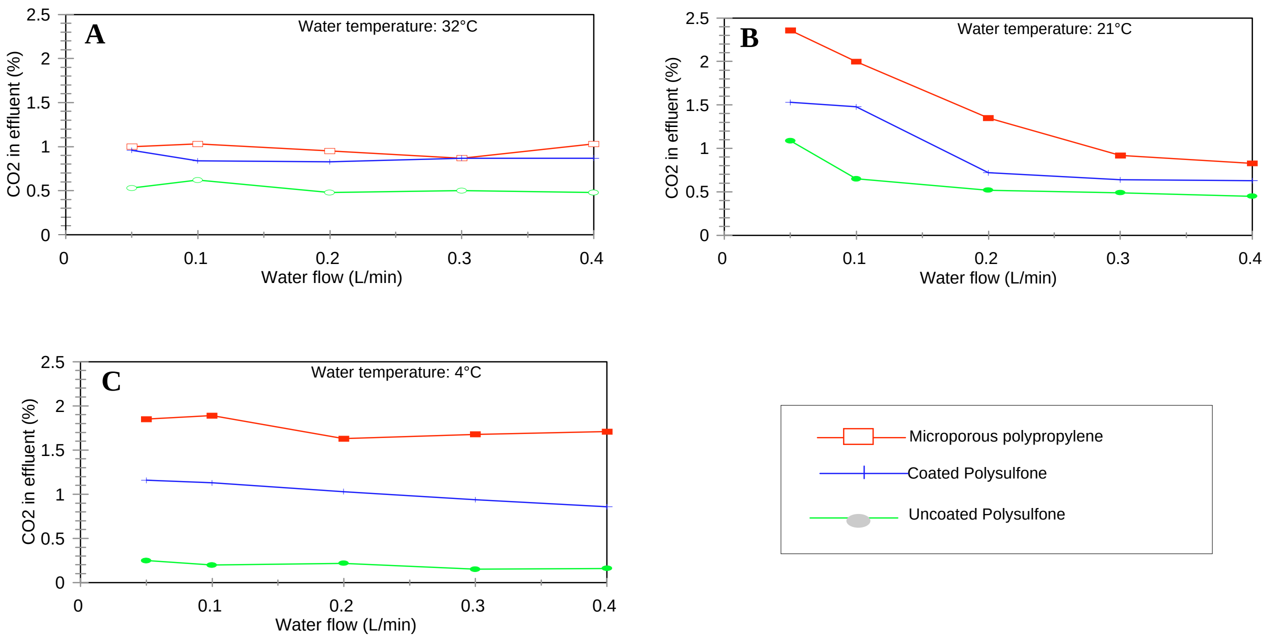

Figure 1. Experimental results from three fiber types at five different flows of fresh water at three temperatures. Panel A shows results from experiments at 32°C, panel B from 21°C, and panel C from 4°C. The inlet gas was 3.96% CO_2, 17.78% O_2 in N_2 at a flow rate of 20 ml/min STPD.

A clear difference can be seen in the performance of the fibers. The uncoated Polysulfone fiber is the best at all temperatures and water flows. Compared to the fiber (microporous polypropylene) that was tested in the first parts of this project, this fiber can reduce the CO_2 in the effluent to less than half. Using this fiber means that the water flow can be reduced substantially. This means that the amount of water flow needed is about 5 to 10 times higher than the amount of gas flow.

The performance of the fibers varies with temperature. If the performance decreased at lower temperatures, it would mean that boundary layer effects were the limiting factor. If the performance decreased at higher temperatures, it would mean that the ability to dissolve the CO_2 was the limiting factor. However, the results from experiments showed that the performance got better at the higher and at the lower temperatures compared to the medium temperature. Experiments at more closely spaced temperatures will be performed to provide empirical data for a theoretical analysis of these observations.

Effects of the Salinity on Exchanger Efficiency

Figure 2 illustrates the effect of the salinity on the exchanger performance. It improves dramatically in salt water.

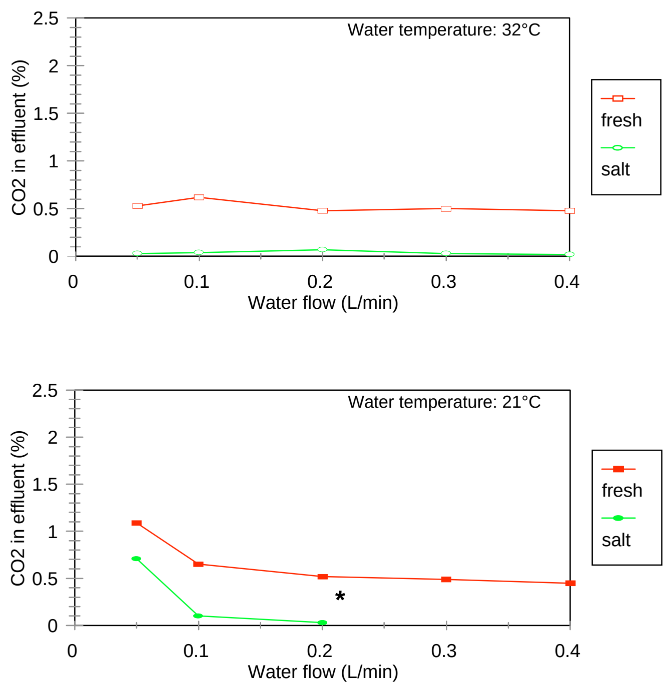

Figure 2. Experimental results from two temperatures and five different flows of fresh and salt water. Panel A shows results from experiments at 32°C and panel B from 21°C. The inlet gas was 3.96% CO_2, 17.78% O_2 in N_2 at a flow rate of 20 ml/min STPD. *A circulation pump failed at this point. Measurements will resume.

Size Estimates of the Frontal Opening of a Full-Scale CO_2 Eliminator

An important aspect of a CO_2 eliminator is size. The following is a worst case estimate of the required opening of a full-scale CO_2 eliminator:

Assume a fiber that requires a water-to-gas flow ratio of 10 and a diver who is swimming fast (about 1.2 knots, 120 feet/min, 36.6 m/min) in fresh water. At this rate the diver would be expected[1] to produce about 2.1 L/min STPD of CO_2. Ventilation of 52.5 L/min BTPS would result. This means a water flow of about 525 L/min through the exchanger. This would mean a frontal surface area of about 140 cm^2 (22 in^2). If the water intake to the exchanger were rectangular and as wide as a person's shoulders (about 40 cm, 16 in), the height of the opening would need to be 3.5 cm (1.4 in). Similarly, if the exchanger were cylindrical, the opening would be a circle with a diameter of 9.6 cm (3.8 in). If the diver were swimming in salt water, it could be made much smaller. Since the CO_2 production is essentially linear with swimming speed, the size of the opening does not change.

The required opening of a full scale CO_2 eliminator should not present a problem.

Inert Gas Loss/Gain

The extra testing equipment has been built and added to the existing testing tower and has gone through early tests. These tests give similar results in CO_2 elimination and give the mass transfer coefficients for O_2 and N_2 as well.

IMPACT/APPLICATIONS

An optimized CO_2 eliminator based on membrane separation has the potential of being inexhaustible while still being about the same size as today's limited endurance CO_2 absorbers based on chemical absorption.

TRANSITIONS

The results from these exploratory bench tests can be put to use in developing full-scale prototype exchange units that would be able to handle a diver's ventilatory requirements. These tests can also be performed at CRESE and can be manned or unmanned at depth. The large-scale unit being built and tested should give information regarding scaling effects. This information will be useful in the manufacturing of the full-scale units should the results continue to be promising.

The manufacturer of the best fiber found so far, has indicated that it expects to be able to manufacture a full-scale unit based on requirements of water flow/resistance and gas flow/resistance should it be decided that such a unit could be feasible.

REFERENCE

[1] Lanphier E., Camporesi E., 1982: *Respiration and Exercise. In: The Physiology and Medicine of Diving*, 3rd ed., p. 100, P.B. Bennet and D.H. Elliot (editors), Best Publishing Company, San Pedro, CA.